A Research Testbed for Virtual Environment Training Applications[1]

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Abstract. This paper describes a research testbed developed to investigate the use of virtual environment (VE) technology for Army training. The objectives of the testbed and the first experiments conducted using the testbed are described, in which performance data was collected as participants completed a variety of basic tasks: vision (acuity, color vision, distance estimation, and search); locomotion (walking and flying through structures); tracking and object manipulation (placing and keeping a cursor on an object, and using it to move objects); and reaction time.

Virtual Environments and Military Training. For many applications, computer-based training simulations provide an inexpensive and safe complement to training with operational systems and equipment. VE technology represents the next generation of simulation-based training. Particularly appealing are the generic nature of VE equipment, its portability and relatively low cost.

The principal component missing from the "electronic battlefield" in today's networked simulation systems is the individual, "dismounted" soldier. The U. S. Army Research Institute for the Behavioral and Social Sciences (ARI) is seeking ways to inject dismounted soldiers into the electronic battlefield. There is little data available on how people perform tasks or learn in virtual environments, or are affected by their exposure. The ARI/IST VE Testbed was established to collect such data.

Basic Tasks, Military-Like and Military Tasks. We need to be able to determine if soldiers can even see a target using our visual display system, before we investigate that system's utility for teaching how to search for that target. We need to know if soldiers can control their own motion well enough, using some motion control like a joystick, to maneuver through a virtual building, before we investigate the use of VE to teach them the layout of the building. We refer to this "axis of complexity" as running from *basic tasks*, through *military-like tasks,* to *military tasks.* This hierarchy is represented in the following figure, with typical tasks and human factors issues at each level.

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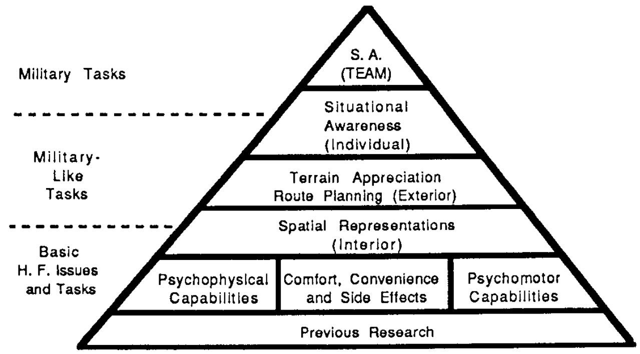

Figure 1: Training-Related VE Research

The ARI Virtual Environment Testbed. ARI considered various requirements in deciding how to construct the VE Testbed. Technical requirements included the following:

- access to a variety of image sources, from low-cost PC's to state of the art image generators
- a substantial capability to generate visual databases, in order to rapidly create experimental training scenarios
- know-how in realtime simulation and VE software systems, so that a variety of interactions could be modeled
- involvement with networked simulation, so that the dismounted infantryman could be inserted into increasingly complex networked battlefield simulation scenarios.
- use of a variety of display and peripheral devices, from low to high fidelity, and their associated tracking and control equipment.
- proximity to an ARI Field Unit, so that ARI psychologists could be intimately involved in the design and execution of experiments.

IST was selected as the Testbed site because it met these criteria. Substantial re-use of equipment owned by the Army's Simulation, Training and Instrumentation Command or donated by manufacturers made IST the most cost-effective site.

The Experiments. Infantry applications share a number of elements: movement through an environment; searching for objects, avoidance of obstacles, navigation through open country and urban terrain and communication with others. There are several specific aspects of VE technology which are important to training and mission rehearsal scenarios for infantry. These include:

> **Visual Displays:** Are some configurations (head mounted, boom mounted or head linked) best suited to perform specific training tasks? What resolutions are required for various classes of tasks?

Immersion[2]**:** Does immersion in a simulated environment improve learning of the configuration, location of objects and routes through the simulated environment or a corresponding real environment?

Database configuration: What visual cues, including object level of detail, scene complexity and realistic scenery, are most important for training transfer?

System Performance: Does sensor lag, sensor transport delay, image generator update rate, effect performance in training?

Side Effects: Are there any adverse side effects from training using virtual environment technology?

Basic Tasks. Our first experiment was conducted to establish a series of relatively simple "benchmark" tasks that we could use to compare the effectiveness of different interfaces into the virtual environment, and train participants on basic VE tasks before requiring them to perform more complex ones. We needed tasks on which performance is:

- reliable (participants perform about the same from trial to trial);
- sensitive to differences in interface devices; and
- sensitive to skill differences among individuals.

In addition, they had to have some face validity with respect to the work of a dismounted soldier, who must move through the environment, communicate with other soldiers, and employ weapons. Categories of tasks included in our initial set were vision, locomotion, object tracking and manipulation, and reaction time.

For the first trials, a pair of PC/486 computers were used to generate a stereo display. Sense8 WorldToolKit software drives Intel's DVI display boards, to produce images consisting of 512 x 512 pixels in 4096 colors. The Virtual Research Flight Helmet has a nominal resolution of 360 x 240 color pixels per eye, with a combined binocular horizontal field of view[3] of approximately 70º and vertical FOV of approximately 37º. A Polhemus IsoTrak system provided head tracking. Participants controlled their viewpoint using either a Gravis joystick or a Spatial Systems Spaceball.

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[2]Immersion is provided by head mounted and head tracking displays as well as localized sound. Viewing a scene via a flat screen is usually non-immersive, although closed simulators such as SIMNET (Alluisi 91) still provide substantial immersion.

[3]This is a narrow-field version of the Flight Helmet. The standard model has approximately a 10º wider field of view. All these FOV values are estimated, and Virtual Research (the manufacturers) do not provide precise numbers.

Participant Preparation. Male and female undergraduate students were recruited through a campus circular, and assigned to one of two groups: joystick or Spaceball. Before participants were tested in the virtual environment, standard vision tests were given to ensure that they had normal vision. Participants then performed four different types of tasks using the Flight Helmet display: vision, locomotion, manipulation and reaction time. The experiment was presented in two sessions each lasting approximately two hours, on subsequent days. In all cases except for the Snellen and color vision tasks, ten presentations of each task were made. After exposure to the virtual environment, the vision tests were re-administered to check for aftereffects.

Vision Tasks. The vision tasks are virtual analogues of the standard vision tests. The efficiency of the VE representation of detail and color was measured by administering VE versions of real-world vision tests, including a Snellen chart and Ishihara color vision charts. A visual search task was presented next, in which the participant had to locate a red ball that appeared anywhere in 3d space around the head.

Locomotion Tasks. The next subset of tasks required the participant to control speed and direction of movement through a series of corridors, doorways and vertical shafts. Motion was controlled either by a joystick or by a Spaceball. When the participant struck the wall of the corridor, forward progress stopped and the participant was required to back up to get un-stuck. Completion times and numbers of collisions were recorded for each of these tasks:

Forward progress through a corridor with 10 alternating 90 degree left and right turns
Forward progress through open doorways (horizontal movement)
Forward progress through open windows (horizontal and vertical)
Forward progress through vertical shafts
Forward progress through curved corridors
Backward and forward progress in a straight corridor

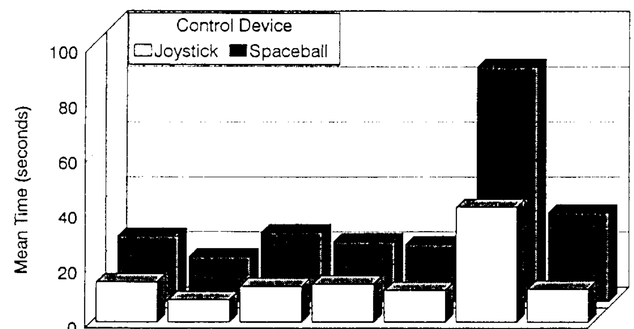
Tracking and Manipulation Tasks. The third subset of tasks, which began the second day of work, involved tracking (with a visible cursor under head or Spaceball or joystick control) and object manipulation. No separate instrumented glove or wand was used; rather, the participant could attach a movable object to the cursor ("pick it up") and move the object and viewpoint together. Tasks included moving objects from bin to bin, manipulation of a slider and manipulation of a dial.

Reaction Time Tasks. The fourth subset of tasks measured reaction times and accuracies. For the simple reaction time test, participants responded to the appearance of an X by pushing the control in any direction as quickly as possible. For the choice reaction time test, the X appeared in one of four locations: up, down, left or right. The participant pushed the joystick or

spaceball in the correct direction as quickly as possible. Accuracy and reaction time were measured for both tasks.

Questionnaires. At the conclusion of all trials, participants completed several questionnaires, including the Essex Corporation Simulator Sickness Questionnaire, to obtain data on side effects.

Results. We analyzed each task separately, using an analysis of variance design with one between-subjects variable (control device) and one within-subjects variable (Trials or Segments). Tasks were scored for both completion time and accuracy. Accuracy was measured by the number of collisions for locomotion tasks, and by successful completions or responses for the others. The most striking results are shown in Figure 2, which shows mean completion time per segment for each of the locomotion tasks as a function of control device. The difference between the two groups was significant for each task ($p<.05$). A similar pattern of completion times was found for the completion tasks. This pattern did not hold for tracking tasks. There were no differences between head and device tracking, or between spaceball and joystick.



	Intro	Back-up	Turns	Doorways	Figure 8	Windows	Elevator
Joystick	14.53	8.11	13.01	13.89	11.58	41.7	11.98
Spaceball	23.54	16.11	24.87	21.53	20.5	85.09	32.27

All differences between Control Devices are significant at $p<.05$

Figure 2: Locomotion Tasks. Mean time per Segment As a Function of Control Device

There were consistent significant practice effects for all manipulation tasks ($p<.05$), but for only two locomotion tasks, the forward progress through the corridor and windows. These were, respectively, the first 2-d locomotion task and the first task requiring subjects to “fly” in 3-d.

Results Concerning Simulator Sickness. Of the 24 subjects, only one became too ill to complete a session. Her data is excluded from Figure 3, which shows the result of the standardized simulator sickness questionnaire. The four clusters of columns correspond respectively to sessions 1 and 2 of our experiments; Kennedy et al’s mean values for their calibration sample of over 1100 Naval aviators who completed the

questionnaire following a training "hop" in any of ten different flight simulators, and the mean scores from the worst of ten simulators in that group (the 2F64c). Clearly, our subjects reported more symptoms than the aviators. Symptoms were also significantly more severe following Session 2 than Session 1 ($p<.05$ for each subscale).

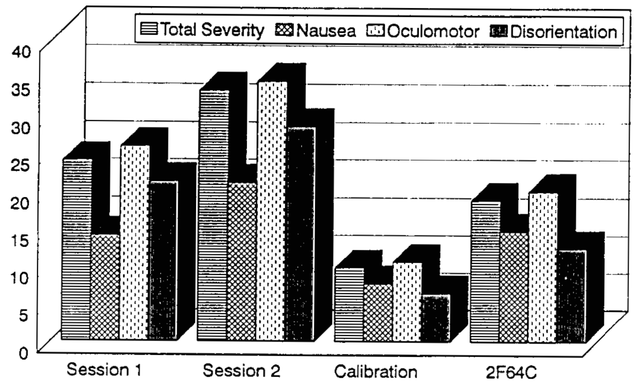


Figure 3: Simulation Sickness Questionnaire Results

Discussion. The objective for this first experiment was to determine if the tasks selected were sensitive to differences in control devices and to practice effects. The Locomotion and Manipulation tasks showed sensitivity to differences in control devices; the Tracking tasks did not. We suspect that the low update rate of our system (about 200 ms for the Tracking tasks) made the tasks so difficult that they could not be performed well with any control device. Overall, participants were able to keep the cursor on the target less than 9% of the time.

We intend to use the joystick rather than the spaceball in our next experiments. However, the results of the comparison of spaceball and joystick must be treated with caution. It is possible that our participants were more familiar with the joystick. Joysticks are common components of video games; spaceballs are not. The same results might not be obtained if use if the results of applying force to the spaceball were immediately apparent (i. e. if the graphics system was faster).

Sensitivity to practice effects was less clear. Only the manipulation and some locomotion tasks showed practice effects. We suspect that this is because we gave participants such little time to practice the locomotion tasks.

The SSQ data show that simulator sickness in VE must be taken seriously, but that it is not a "show stopper." Despite the limits that we placed on exposure, we found that most participants reported some symptoms. There is a lack of other data to use for comparison. We do not know what the behavioral consequences of the exposure are. Is balance affected? We know

that our subjects reported more symptoms than Navy Aviators after simulator use, but Navy aviators are very different from college students.

There are several reasons why reported symptoms might have been more severe after the second session than after the first. The questionnaire may be a "reactive measure. That is, completing it once after the first session may cause the participant to be more aware of their symptoms during the second session. There may be a cumulative effect of repeated exposures. The tasks in the second session (but not the first) involved "flying", or vertical movement, which may have also made a difference. The use of a slow, low-resolution system may have contributed to these findings. We look forward to learning more as our equipment improves. We also plan to collect data on postural stability in future experiments, to provide a behavioral indication of effects.

Future Research. The second experiment using the assessment battery, for which we have completed data collection, is examining how the control device effects that we obtained in the first experiment change with extended practice. We are also examining the use of postural stability as a measure of simulator sickness. The third experiment will look at the effects of different display modes (monitor, high resolution head tracked display and low resolution head mounted display) on performance on the same tasks. A model of an office building is currently under development, which will represent the exterior and 25% of the interior of an actual 65,000 square foot office building. We will conduct experiments investigating the use of this model to teach the configuration of and routes through the building. Since it is an actual building, we will be able to test how well knowledge acquired in the virtual building transfers to the real world.

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